New Estimate of Number of ν_e CC Interactions in the 203 Set

Introduction

The number of ν_e CC interactions is an important number in the understanding of the data set. Not only does it provide a measure of a category of interactions, which needs to be confirmed, but it also provides information for determining the number of interactions fro the non-prompt component of ν_μ. The ν_e component is almost completely free of any contamination due to π or K decays. Thus it may also provide an independent check of the momentum spectrum of muons. In note we will try to extract the number of ν_e CC interactions only.

Method

The method has been described before, so we will go over it only briefly here. The energy spectrum from the calorimeter is used exclusively in these measurements. Two data subsets (from the 203) are defined: (1) the identified ν_μ CC subset and (2) events not in (1). The second subset ought to contain most of the ν_e CC events as indicated by relatively large energy deposits in the calorimeter. The ν_μ CC events will deposit a smaller amount of energy, almost all coming from the π^0 s in the hadronic recoil of the interaction. Because of the thickness of the targets, we will use only those events with interactions in module 3 or 4. The average energy loss is typically <35% for module 3 interactions, and <20% for module 4. Because the losses are small, the average corrections determined from the Monte Carlo are expected to be reliable.

From a sample of 208 located events (which includes the 203 set) four subsets of data are defined for this analysis:

1) Module 3 identified ν_μ CC interactions
2) Module 3 not ν_μ CC interactions
3) Module 4 identified ν_μ CC interactions
4) Module 4 not ν_μ CC interactions

In order to estimate the number of ν_e CC events in the data (2) or (4), we need to subtract the part of the calorimeter spectrum due to NC interactions and unidentified ν_μ CC interactions. These spectra are expected to be much lower energy than the true ν_e CC spectrum and are assumed to have the same shape. We estimate this spectrum using the ν_μ CC spectrum (separately, from each module). First, the E_{cal} spectrum from subset (1 or 3) is normalized such that the number of NC events, N_{NC}, and the unidentified ν_μ CC events, N_{miss}, are related to the number of ν_μ CC events, $N_{\mu CC}$, by

$$\begin{aligned} N_{not\,\mu} &= N_{NC} + N_{miss} \\ &= aN_{\mu CC} + bN_{\mu CC} \end{aligned}$$

Given that the ratio of NC to Total interactions is 0.21, the value of a = 0.45. Also given that the Muon ID efficiency is 0.80, then b = 0.20, so that we need to change to the normalization of the ν_μ CC energy distribution to $0.66\times N_{\mu CC}$. This is done individually for module 3 and module 4 data. The estimated background spectra from each module (expected to be mostly NC) are first subtracted from the spectra from subsets (2) and (4).

Next, an low-energy cut is made on the distributions based on MC generated spectra of the total energy in the calorimeter. This cut is defined as keeping 83% of the total generated number of events. The values used are 20 GeV for module 4 events and 13 GeV for module 3. The two procedures, spectra subtraction and energy cut, are expected to remove most of background to the ν_e CC events. Actually, the energy cut would not be necessary, except that there is an excess of interactions in module 4 which produce little energy in the calorimeter. Therefore, either there are more NC events in module 4, or there are a type of event that is poorly understood at this time.

Results

The ν_e CC signal is clearly apparent in Figure 1 and 2, which show the calorimeter spectra in all four modules for the identified muon sample (Fig. 1) and the NOT.muon sample. The NOT.muon spectra for modules 3 and 4, after the NC spectrum subtraction is shown in Fig. 3. Note that the module 3 spectrum is similar to what one would expect, with fewer events in the low-energy bins. But this is not the case for the module 4 subtracted spectrum, where there is an excess of low-energy events. This excess is estimated to be 11 events, by comparing the MC expected spectrum to the subtracted one. These low-energy events need to be examined and categorized.

Now, we use the subtracted *and* cut spectrum for module 3 and 4 (cut at 13 and 20 GeV respectively) to extract the estimate for the number of ν_e CC interactions. In the module 3 (4) data, 16.4 (8.8) events are above the energy cut. The number of events in module 3 (4), corrected by the energy cut is 19.4 (10.3). The total number of ν_e CC events expected in the sample of 203 events is computed from the relative number of events expected, based on the product of target mass and POT, as shown in Table 1. From the table, we have 49.1% of the interactions are expected in the sum from Stations 3 and 4. Therefore the estimated total number of ν_e CC events from this analysis is,

Sta / Per	1	2	3	4	Σ
1	5.7	0.	5.7	0.	11.4
2	4.7	0.	4.7	3.1	12.5
3	10.9	7.4	7.4	7.4	33.1
4	11.4	11.4	11.4	9.4	43.6
Σ	32.7	18.8	29.2	19.9	100.

Table 1. The percentage of events expected at each station and data period.

$$N(\nu_e) = \frac{19.4 + 10.3}{0.491} = 60.5$$

The statistical uncertainty in this number is based on the sum of the events in modules 3 and 4, 25.2 events, or 20%. There is a systematic uncertainty that must take into account the poorly understood, low-energy part of the module 4 spectrum. Until this excess is explained, we must add an error from the 11 “excess events” , or 11/60.5 = 18%. Therefore, the final estimate for the number of ν_e CC events is,

$$\boxed{N(\nu_e) = 60.5 \pm 12.1(stat) \pm 10.9(sys)\ \text{ events}}$$

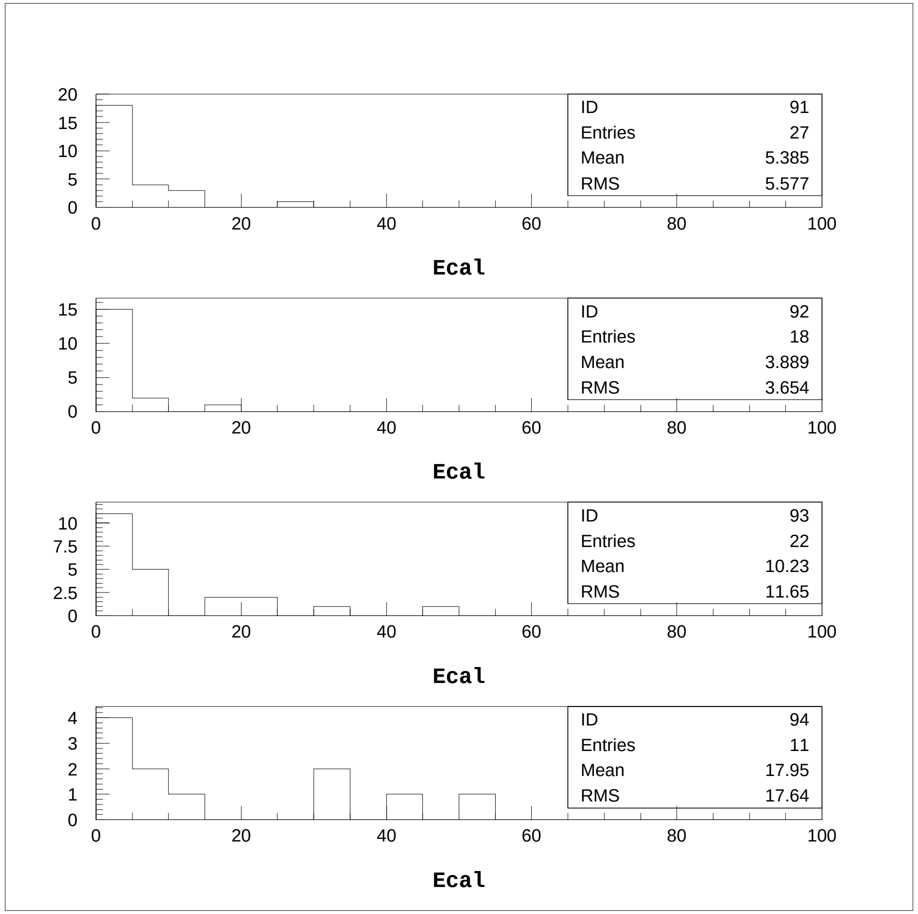

Figure 1. The calorimeter spectrum for events with an identified muon, in Station 1 (*top*) through 4 (*bottom*).

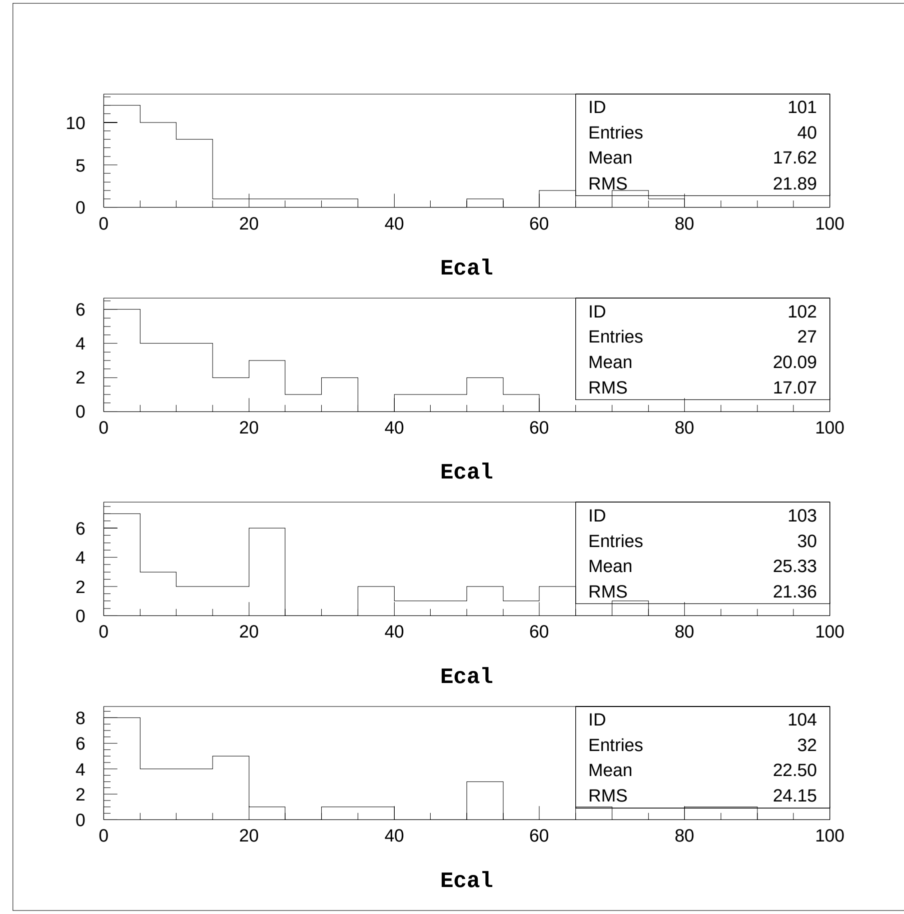

Figure 1. The calorimeter spectrum for events without an identified muon, in Station 1 (*top*) through 4 (*bottom*).

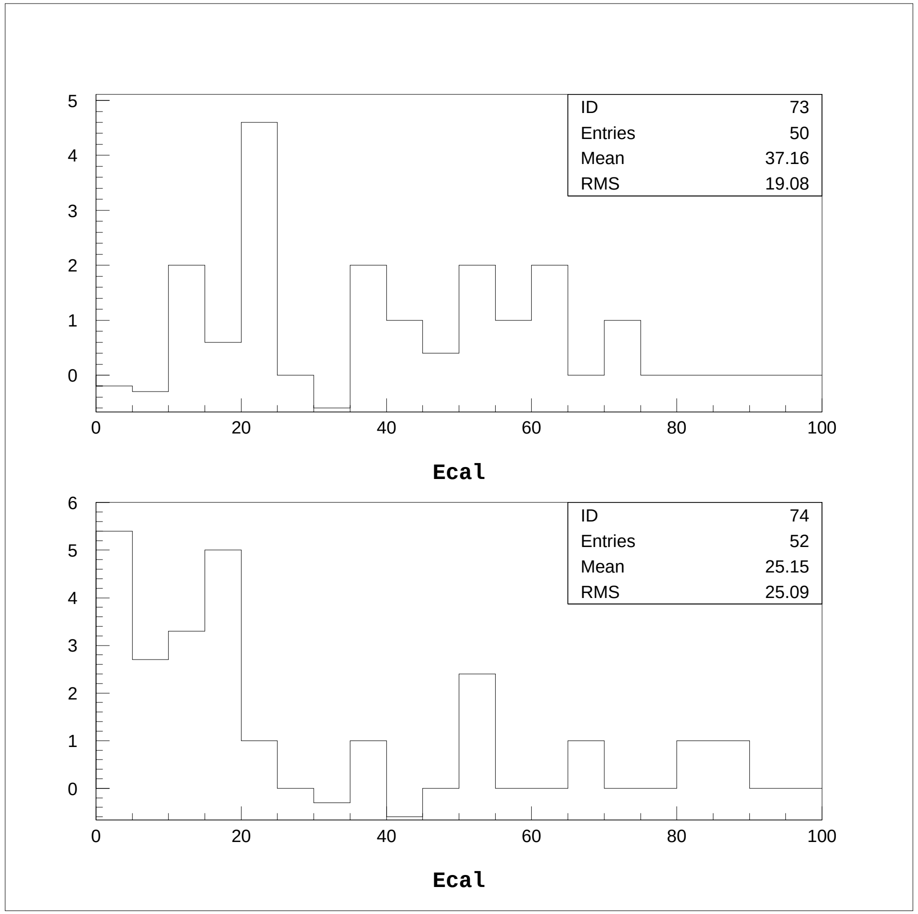

Figure 3. The subtracted calorimeter spectra for Station 3 (*top*) and Station 4 (*bottom*). Note the excess of events in low-energy part of the Station 4 data.